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A PROPANE POWERED AUTOMOBILE FOR LOW AIR POLLUTION EMISSIONS. PART I

Floyd Sam, et al

California University

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A PROPANE POWERED AUTOMOBILE FOR LOW AIR POLLUTION EMISSIONS

Part I

Floyd Sam

Thermal Systems Division
Department of Mechanical Engineering
University of California
Berkeley, California 94720

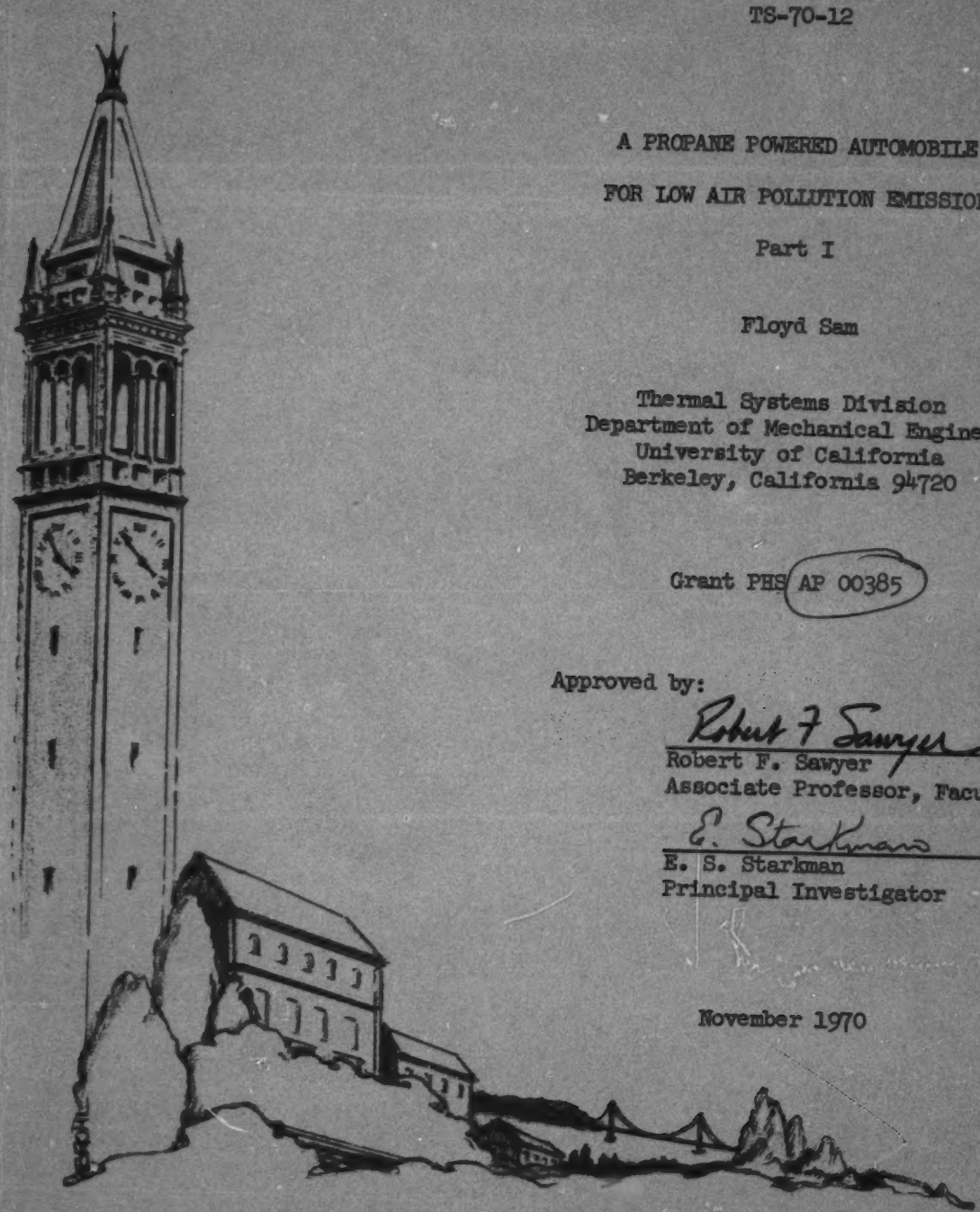
Grant PHS AP 00385

Approved by:

Robert F. Sawyer
Robert F. Sawyer
Associate Professor, Faculty Advisor

E. Starkman
E. S. Starkman
Principal Investigator

November 1970



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A PROPANE POWERED AUTOMOBILE FOR LOW AIR POLLUTION EMISSIONS

PART I

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Floyd Sam, Research Assistant

Thermal Systems Division
Department of Mechanical Engineering
University of California
Berkeley, California 94720

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Abstract

A 1970 Plymouth Belvedere, 4-door sedan with 318 C. I. D. engine, was prepared as an entry for the 1970 Caltech - MIT Clean Air Car Race from MIT to Caltech. The major modifications to the original vehicle included conversion of the fuel system to utilize liquified propane (including all related appurtenances), two catalytic exhaust reactors, and an exhaust gas recirculation system.

This particular combination of systems has proven to be especially conducive to low exhaust emissions of unburned hydrocarbons (HC), nitrogen oxides (NO_x), and carbon monoxide (CO).

The emission levels attained by this vehicle during the qualifying tests at Olson Laboratories, Inc. on July 10, 1970 were:

	HC	CO	NO_x
Composite	23 ppm	0.00%	222 ppm
Mass Equivalents gm/mi	0.31	0.00	0.86

For comparison, the 1975 Federal standards for automotive emissions levels are as follows:

	HC	CO	NO_x
Mass Equivalents	0.50 gm/mi	11.0 gm/mi	0.9 gm/mi

PREFACE

The University of California Propane Car was initiated as a design project for a senior mechanical design class during the Winter Quarter of 1970. The actual construction of the car was accomplished during a senior laboratory class under the auspices of Professor Robert F. Sawyer.

The actual construction is the result of a team effort on the part of seven mechanical engineering students-Floyd Sam, Charles Simkins, Darrell Erikson, Gary McCauley, Bak-Ying Chan, Steven Clauson, and Shahriar Kashanchi. In addition, the full support of the University of California Hesse Hall Machine Shop and many industrial organizations helped to make the Propane Car a reality.

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INTRODUCTION

This world has been taking greater cognizance of the air pollution situation. On numerous occasions, the detrimental aspects of air pollution with respect to health, agriculture, materials, and aesthetics have been demonstrated. The greatest contributor to the problem of atmospheric pollution is the automobile. It produces the greatest total percentage of unburned hydrocarbons, nitrogen oxides, and carbon monoxide. In 1966, the automobile produced approximately 86,000,000 tons of pollutants--60.6% of the total amount produced from all major sources.[1]

Intense efforts have been directed towards developing modifications to the present internal combustion engine for reducing its emission levels. These efforts have resulted in the development of systems such as exhaust manifold reactors (thermal), timed air injection, exhaust gas recirculation, catalytic exhaust reactors, fuel additives, alternative fuels, and modifications to engine operating parameters such as spark timing, compression ratio, spark location, spark duration, combustion chamber geometry, etc.

Alternative power systems have also come into consideration. Other prime-mover systems investigated for use include gas turbines, electric motors (fuel cells and exotic batteries), external combustion engines (steam, stirling, etc.), and hybrid combinations of these.

Finally, development of efficient mass transportation systems has been encouraged. This is especially attractive for large urban and business areas to not only reduce air pollution, but to relieve traffic congestion.

Many of these ideas may become a commercial reality in the more distant future, but for an immediate solution, the use of a fuel alternative to gasoline appears to be the most attractive. The fuel alternative considered in this project was liquid propane. Propane fueled engines have substantially lower emissions levels than gasoline fueled engines. This results largely from the fact that propane burns more completely and cleanly than gasoline. As an attestment to the lower levels of emissions produced by propane, many corporations and cities have converted their fleet vehicles to utilize propane fuel.

The vehicle in this report has been converted to run on propane. In addition to this modification, the exhaust system has been modified to accommodate two catalytic exhaust reactors and an exhaust gas recirculation system. This combination of systems has proven to substantially reduce engine exhaust emissions to levels below the 1975 standards for the State of California. Figure 1 provides an overall schematic of the emission reduction system for the Plymouth Belvedere used.

Coupled with low pollution emissions, propane powered vehicles offer lower fuel costs (approximately 26¢ per gallon including road tax), and extended engine life resulting from lack of deposit build-up present with gasoline combustion.

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1 "The Automobile and Air Pollution: A Program for Progress," Part II, Dec. 1967, pg. 41

SYSTEM DESCRIPTION

Fuel System:

An Impco propane carbueretor, Model 225 was selected for use on the 318-C.I.D. Plymouth Belvedere, replacing the original 2-barrel gasoline carburetor. In addition, a Model E converter-regulator and Mylander Filter Fuellock were used to convert the liquefied propane to a gas and to check fuel flow.

Figure 2 is a piping layout of the fuel system excluding tanks. The fuel tanks are a dual-manifold set supplied by the Manchester Tank Co., with a total capacity of 34.6 gallons.

The liquid fuel enters the fuel lock at tank pressure (100-120 psig) and then passes into the converter. Figures 3 and 4 show the converter in detail. Here the liquid fuel is converted to a gas in the vaporizing chamber and exits at a reduced pressure of approximately 1.5" W.C. vacuum. Heat for the vaporizer is supplied by the engine cooling water system and jackets the various passageways of the converter.

Since propane boils at -44^{o} F, there is sufficient temperature differential even under cold-start conditions for the engine coolant-system water to satisfactorily perform this function. A primer is provided for extremely cold starts.

The gas then passes through the secondary or low pressure valve which is controlled by the low pressure diaphram and into the low pressure chamber where it is drawn off through the gas outlet to the carburetor. The gas flow through the carburetor is controlled by a special air-gas valve developed by Impco.

Air flow is measured by an air flow measuring valve in the bowl of the carburetor--the higher the air flow measuring valve rises, the greater the air flow. The gas metering valve is connected directly to the air valve so it rises exactly the same amount. The gas valve is shaped to admit the correct amount of gas at any height to which the air flow measuring valve rises, thus giving the correct air-fuel mixture at all times.

In addition, the air-gas valve provides a method of sealing off the fuel at rest thus eliminating "evaporative" losses, which can contribute up to 25% of the total (HC) emissions on gasoline fueled cars, and acts as a choke for fast starts.

Exhaust Recirculation System:

Nitrogen oxide formation is strongly a function of peak combustion temperature. Lowering of the peak combustion temperatures results in a significant decrease in nitrogen oxide emissions. This is the major consideration associated with the use of an exhaust gas recirculation system. However, it should be noted, from combustion theory, there is a trade-off between HC and NO_x emissions by varying the peak combustion temperature.

A portion of the exhaust gases is picked up down stream of the exhaust manifold and returned to the carburetor as a "bulk" gas. The role of the recycle gas is to "absorb" energy during combustion, thereby lowering the peak temperatures.

The recycle system installed on the race entry utilizes 3/4" copper tubing as the return line. The tube is introduced into the exhaust stream and is constructed in such a fashion that an impact effect exists.

This aids in attaining a sufficient exhaust flow to the carburetor. The exhaust then flows to a valving system mounted in the engine compartment. The upstream valve is a butterfly valve to regulate flow rates--the down-stream valve is a simple on-off solenoid operated check valve which prevents recycle flow during idle and full throttle. Recycle is not desirable during these two modes because of rough engine operation during idle and power reduction during full throttle.

From the valving, the exhaust gas flows into the carburetor at a point just above the carburetor butterfly (throttle) valve. This point has a near-constant vacuum varying between .5" and 1" of mercury during all operating modes.

Figure 5 provides a detailed schematic of the recycle system installed in the race entry.

Catalytic Exhaust Reactors:

Two catalytic exhaust reactors were installed in the exhaust system for the reduction of unburned hydrocarbons and carbon monoxide emissions. The mufflers are model PTX-5 supplied by the Englehard Chemical and Minerals Company. The original exhaust system was modified to provide for reduced back-pressure and smooth the exhaust flow.

The mufflers operate most effectively in the temperature range of about 800 F to 1400 F. To accommodate this requirement, the mufflers were mounted as close as practical to the exhaust manifolds. The point selected is located approximately 2 feet from the exhaust manifolds. To help maintain the heat, the sections of exhaust pipe between the manifolds and mufflers have been wrapped with asbestos gauze.

A balance pipe was installed just up-stream of the catalytic mufflers to stabilize and assure an even exhaust flow through both mufflers.

The two sections of exhaust pipe meet in a Y-connection at a point about 3 feet down-stream of the mufflers and combine into a single exhaust pipe. From here, the gases flow through a conventional muffler to minimize noise, which is also regarded as a pollutant, and out to the atmosphere.

The catalytic muffler operates in such a manner that when sufficient air is present, the catalyst reacts the unburned hydrocarbons and carbon monoxide with the air. The engine of the test vehicle is operated at fuel lean conditions over most modes, approximately .8--1.0 equivalence ratio, to assure sufficient air for the reaction.

Additional Modifications:

To further reduce the peak combustion temperature, thereby lowering the NO_x emissions, the heat risers to the intake manifold were blocked. The heat control valve in the passenger-side exhaust manifold was also removed.

Since leaner fuel mixtures are being used, a capacitive discharge ignition system was installed to assure more consistent mixture ignition. Conventional ignition systems are often inadequate to promote lean mixture ignition.

Valves often do not seat when propane is utilized as the fuel. To prevent this problem, the valves were ground and lapped into place in the heads. This prevents, in particular, rough engine performance resulting from exhaust back-flow into the intake manifold.

Since the air density in the engine compartment changes as tne engine reaches operating temperatures, the air-fuel mixture ratio also varies. To help relieve this problem, and to provide for a more constant air-fuel mixture, air for combustion is collected by an air scoop installed below the front bumper. This should also assist in

lowering the peak combustion temperature, as ambient air is cooler than air from the engine compartment.

Figures 6-14 are photographs of the car and various components of the "clean air system."

TEST RESULTS

On July 10, 1970, the race vehicle was brought to Los Angeles for emissions testing at the Olson Laboratories Mobile facilities. The emissions levels were:

	HC	CO	NO_x
Composite	23 ppm	0.00%	222 pm
Mass Equivalents	0.31 gm/mi	0.00 gm/mi	0.86 gm/mi

The 1975 Federal Standards are given as follows:

	HC	CO	NO_x
Mass Equivalents	0.50 gm/mi	11 gm/mi	0.90 gm/mi

However, to better appreciate the emissions levels attained by this particular vehicle, these values should be compared to the emissions from this engine before modifications. Ten 1970 Chryslers with 318 C. I. D. engines were measured for emissions levels by the California Air Resources Board and the following average levels were recorded.

	HC	CO	NO_x
Average	1.84 gm/mi	7.83 gm/mi	6.97 gm/mi (1848 ppm)

Comparing these values to those measured for the race vehicle, the following precent reductions were realized:

	HC	CO	NO_x
% Reduction from Conventional System	83%	100%	88%

At the time of testing the ignition spark timing was set at 5 ATDC, the compression ration was 8.8:1, and approximately 15% of the exhaust gases was being recycled.

One point noted during the testing was a decrease in power of the vehicle when the recycling was introduced. The precise percentage power reduction was not determined, but at high recycle rates, i.e., approximately 20% or greater, the car had some difficulty performing the acceleration modes of the California 7-mode cycle tests, particularly the 15-50 mp in 29 seconds acceleration mode.

The specific fuel consumption was measured in previous tests. At conditions of approximately 50 mph, 1900 rpm, and 8.8 hp., the fuel consumption was measured to be about 17.5 lbm/hr. This value varies with the degree that the engine is de-tuned to attain lower emissions; however, variations from this value should be small. In terms of crusing range, this corresponds to approximately 11 miles/gallon for gasoline fueled vehicles.

CONCLUSIONS

1. The combination of a propane fuel system, catalytic exhaust reactors, and an exhaust gas recirculation system does result in a significant reduction of emissions from a conventional internal combustion engine vehicle. The test vehicle of this paper attained levels of .31 gm/mi HC, 0.00 gm/mi CO, and .86 gm/mi NO_x.
2. Propane fuel is conducive to longer engine life through cleaner and more efficient combustion.
3. An exhaust gas recirculation system results in an engine performance loss.
4. On a mass production basis, low pollution vehicles could be manufactured for a nominal cost.

LIST OF FIGURES

Fig. 1. Overall System

Fig. 2. Piping Layout-Propane Fuel System

Fig. 3. Model E Vaporizer-Regulator

Fig. 4. Model E Vaporizer-Regulator and Carburetor Hook-Up

Fig. 5. Exhaust Gas Recirculation System

Fig. 6. University of California "Clean Air Car"

Fig. 7. Liquid Propane Fuel Tanks

Fig. 8. Filter-Fuellock

Fig. 9. Vaporizer-Regulator

Fig. 10. Insulated Catalytic Mufflers on Car

Fig. 11. Propane Carburetor and Exhaust Recycle Inlet

Fig. 12. Insulated and Uninsulated Catalytic Mufflers

Fig. 13. Exhaust Recycle Extraction Point

Fig. 14. Exhaust Recycle Valving Arrangement

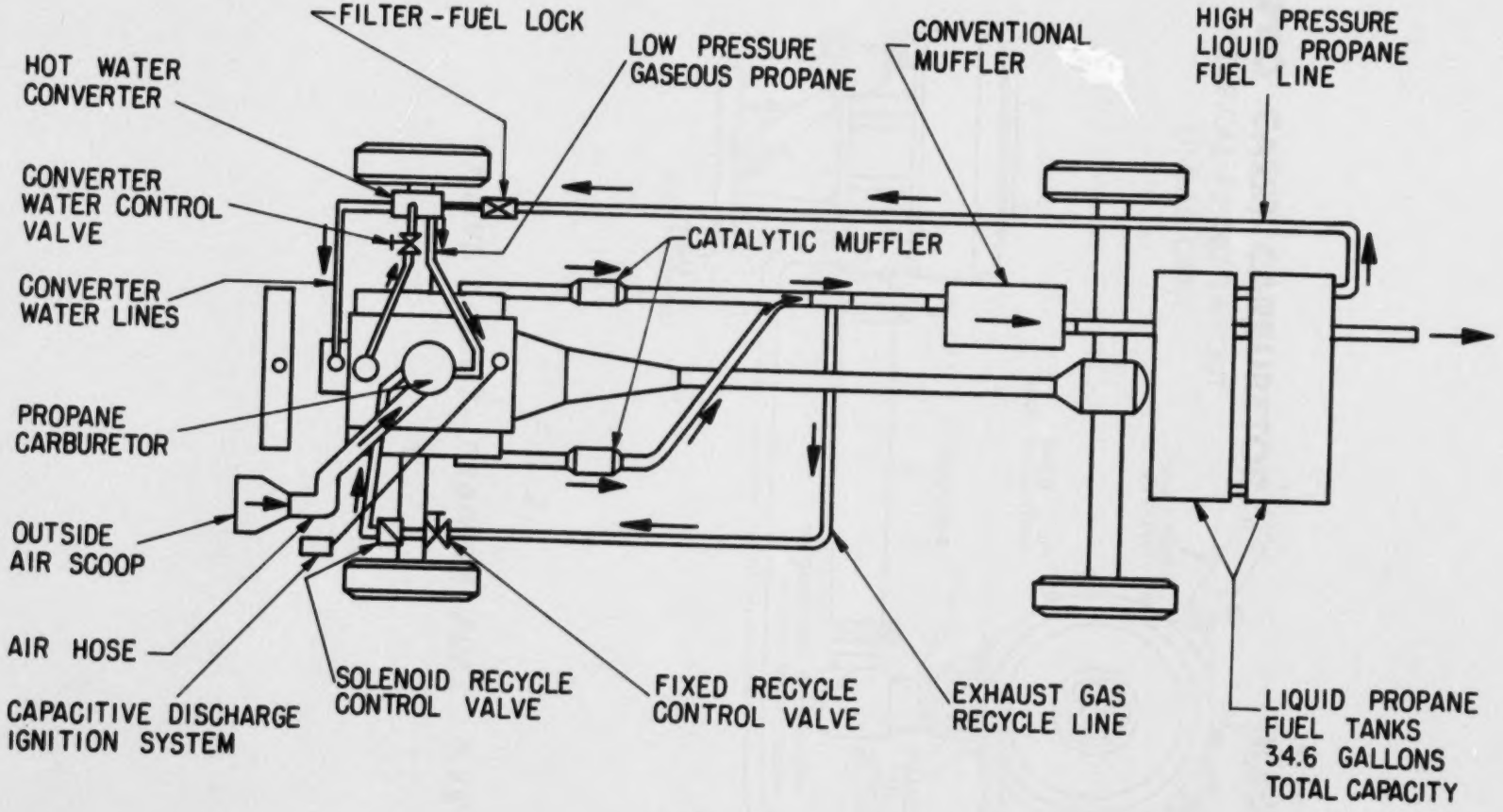


FIG. 1.

SCHEMATIC OF UC PROPANE CAR EXHAUST EMISSIONS CONTROL SYSTEM

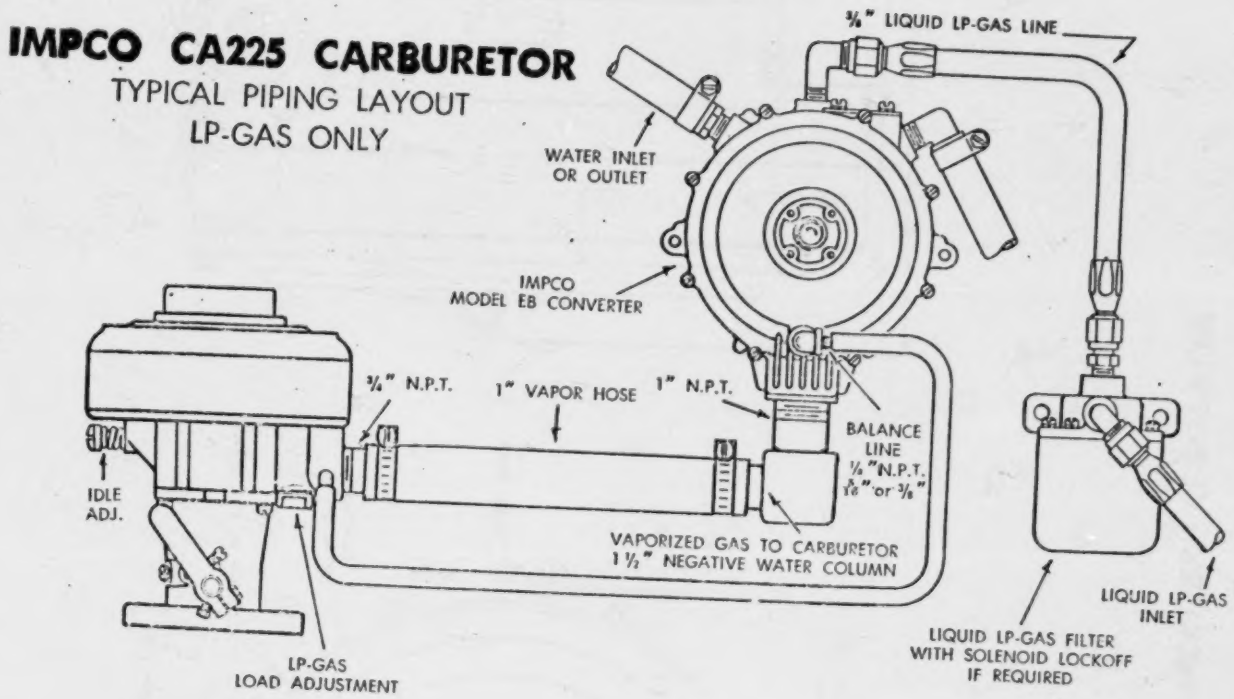
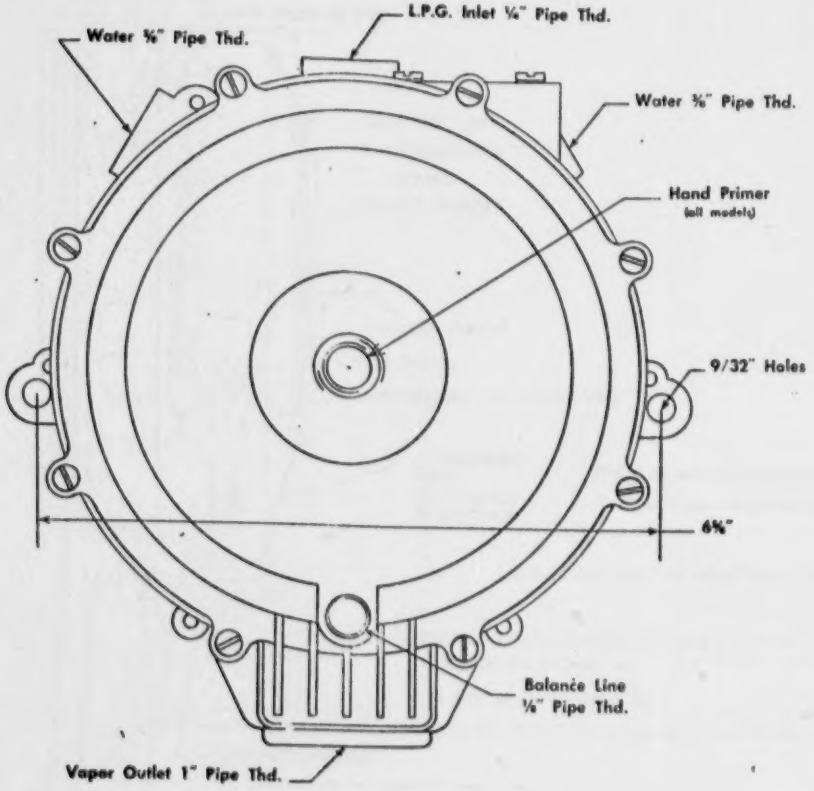


FIG. 2.

PIPING LAYOUT- PROPANE FUEL SYSTEM



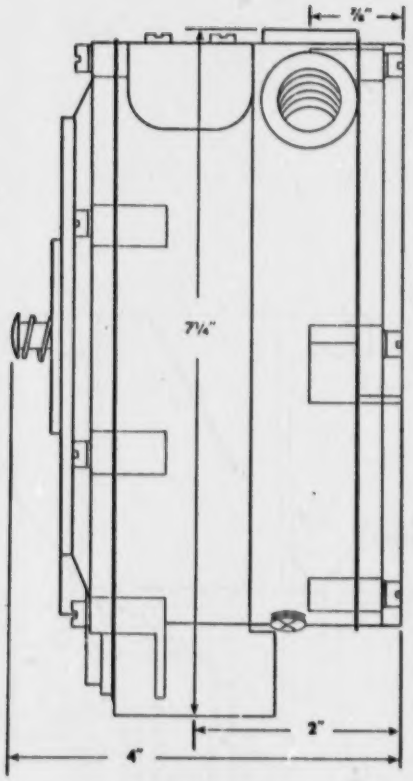


FIG. 3.

MODEL E VAPORIZER - REGULATOR

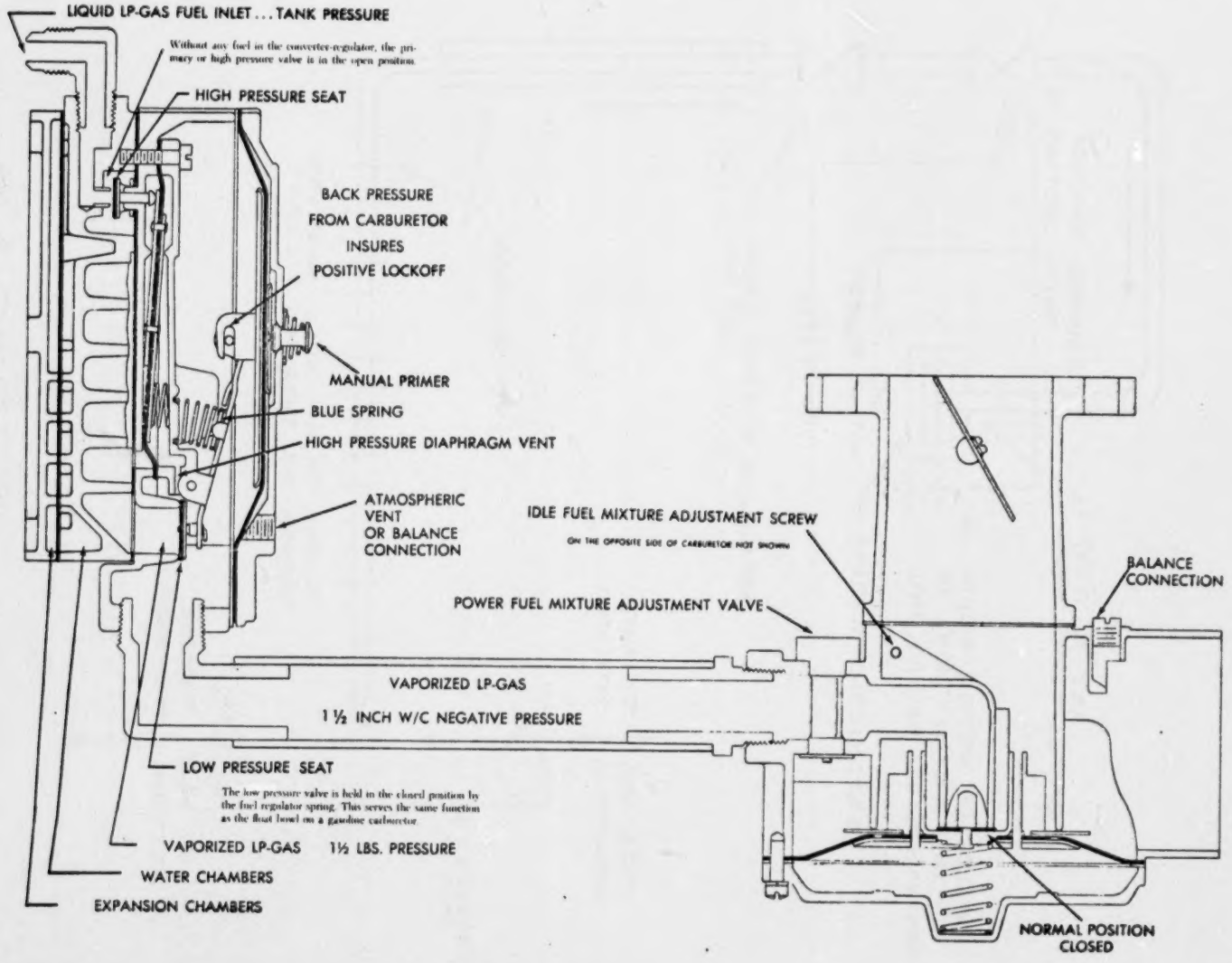

LIQUID LP-GAS FUEL INLET ... TANK PRESSURE
Without any fuel in the converter-regulator, the primary or high pressure valve is in the open position.
HIGH PRESSURE SEAT
BACK PRESSURE FROM CARBURETOR INSURES POSITIVE LOCKOFF
MANUAL PRIMER
BLUE SPRING
HIGH PRESSURE DIAPHRAGM VENT
ATMOSPHERIC VENT OR BALANCE CONNECTION
IDLE FUEL MIXTURE ADJUSTMENT SCREW
ON THE OPPOSITE SIDE OF CARBURETOR NOT SHOWN
BALANCE CONNECTION
POWER FUEL MIXTURE ADJUSTMENT VALVE
VAPORIZED LP-GAS
1 ½ INCH W/C NEGATIVE PRESSURE
LOW PRESSURE SEAT
The low pressure valve is held in the closed position by the fuel regulator spring. This serves the same function as the float bowl on a gasoline carburetor.
VAPORIZED LP-GAS 1½ LBS. PRESSURE
WATER CHAMBERS
EXPANSION CHAMBERS
NORMAL POSITION CLOSED

FIG. 4.

MODEL E VAPORIZER-REGULATOR AND CARBURETOR HOOK-UP.

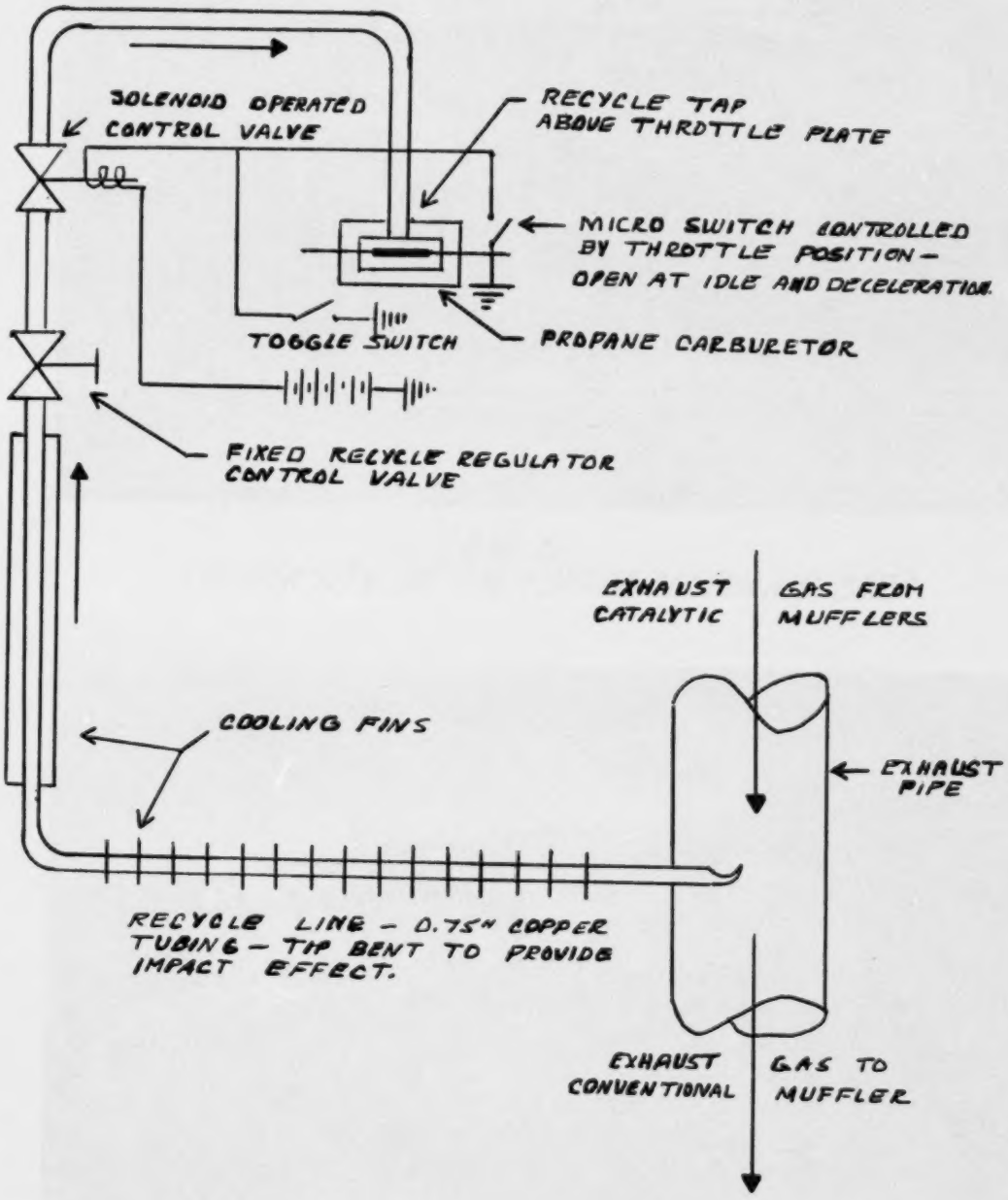

SOLENOID OPERATED CONTROL VALVE
RECYCLE TAP ABOVE THROTTLE PLATE
MICRO SWITCH CONTROLLED BY THROTTLE POSITION – OPEN AT IDLE AND DECELERATION.
TOGGLE SWITCH
PROPANE CARBURETOR
FIXED RECYCLE REGULATOR CONTROL VALVE
EXHAUST CATALYTIC
GAS FROM MUFFLERS
COOLING FINS
EXHAUST PIPE
RECYCLE LINE – 0.75" COPPER TUBING – TIP BENT TO PROVIDE IMPACT EFFECT.
EXHAUST CONVENTIONAL
GAS TO MUFFLER

FIG. 5. EXHAUST GAS RECIRCULATION SYSTEM

FIG. 6.
UNIVERSITY OF CALIFORNIA "CLEAN AIR CAR"

FIG. 7.
LIQUID PROPANE FUEL TANKS

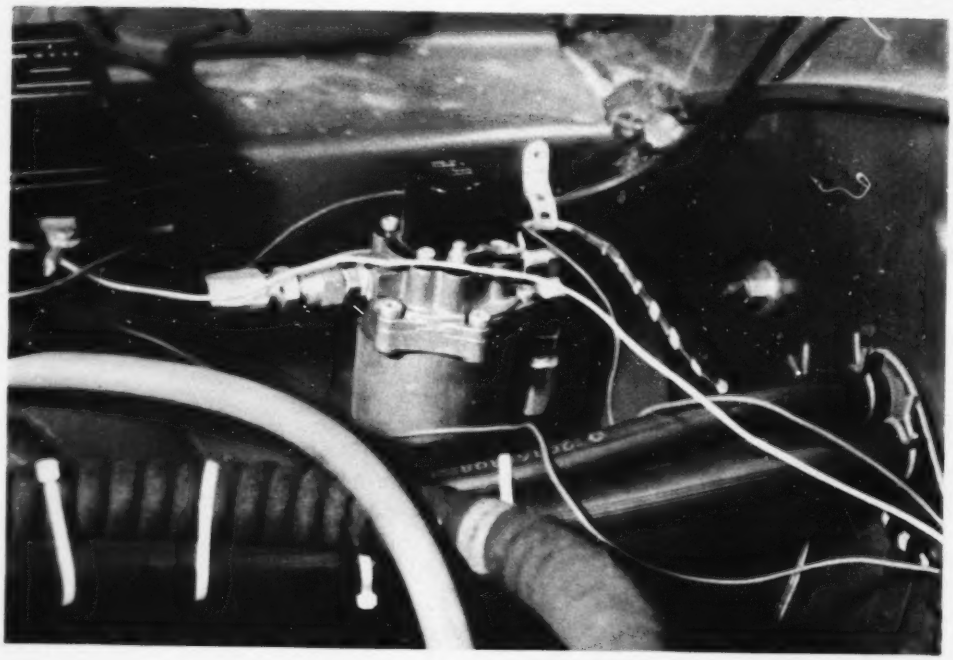


FIG. 8.
FILTER-FUELLOCK

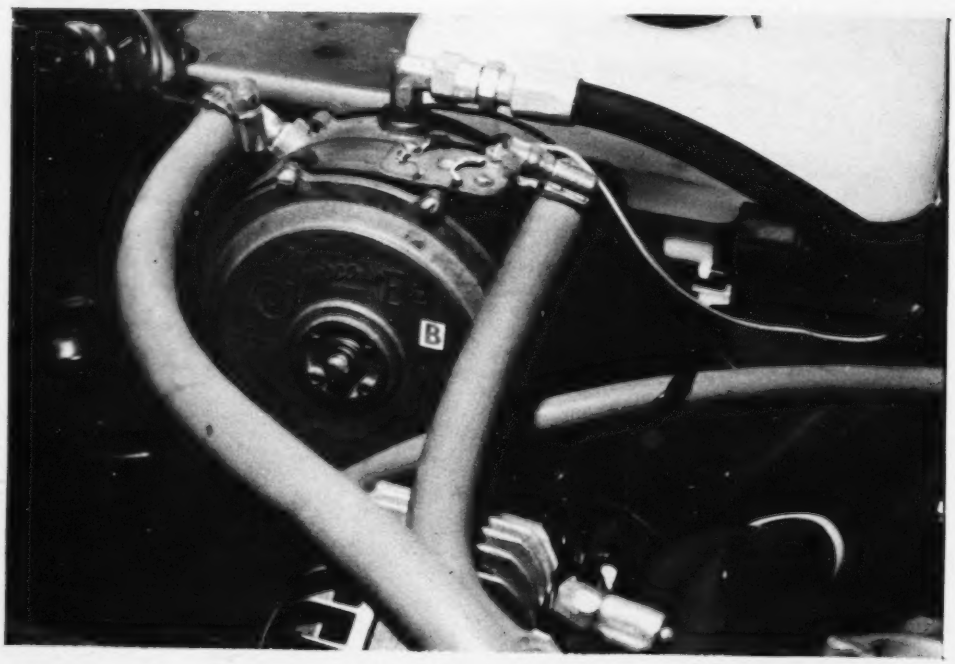


FIG. 9.
VAPORIZER REGULATOR

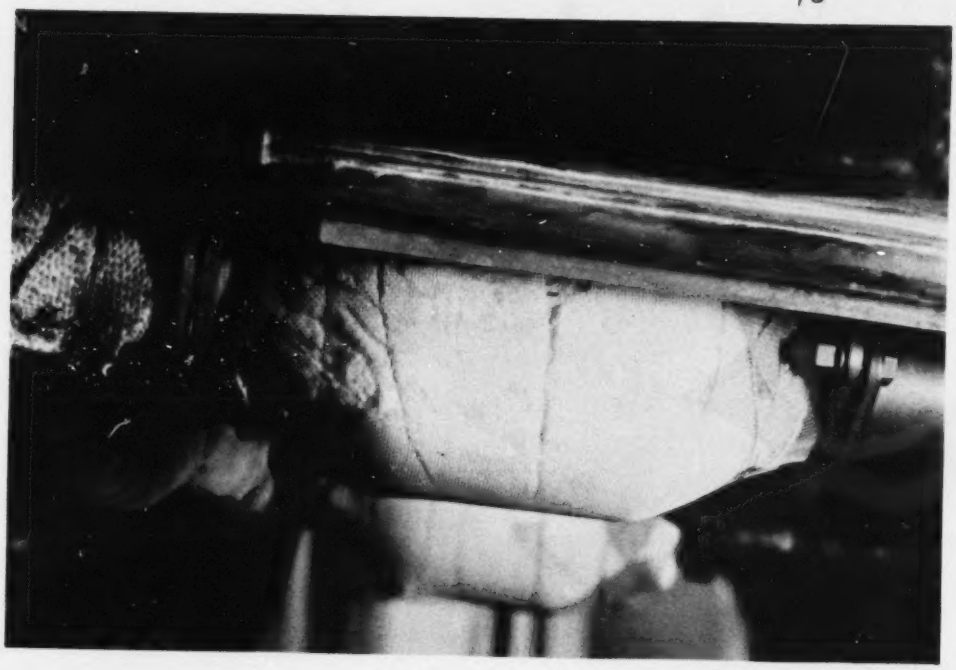


FIG. 10.
INSULATED CATALYTIC MUFFLERS ON CAR

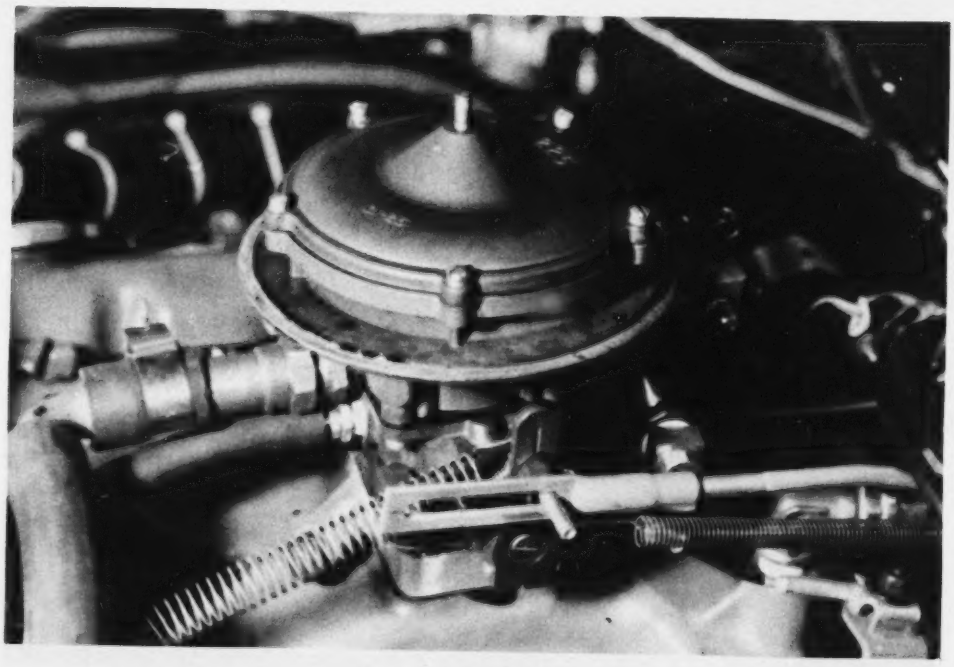


FIG. 11.
PROPANE CARBURETOR AND EXHAUST RECYCLE INLET

FIG. 12.
INSULATED AND UNINSULATED CATALYTIC MUFFLERS

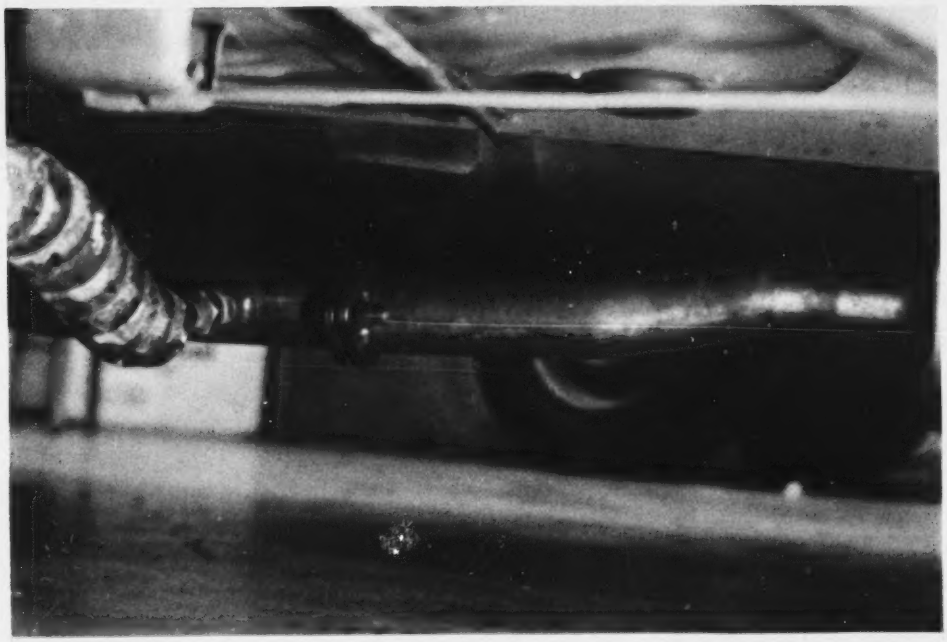


FIG. 13.
EXHAUST RECYCLE EXTRACTION POINT

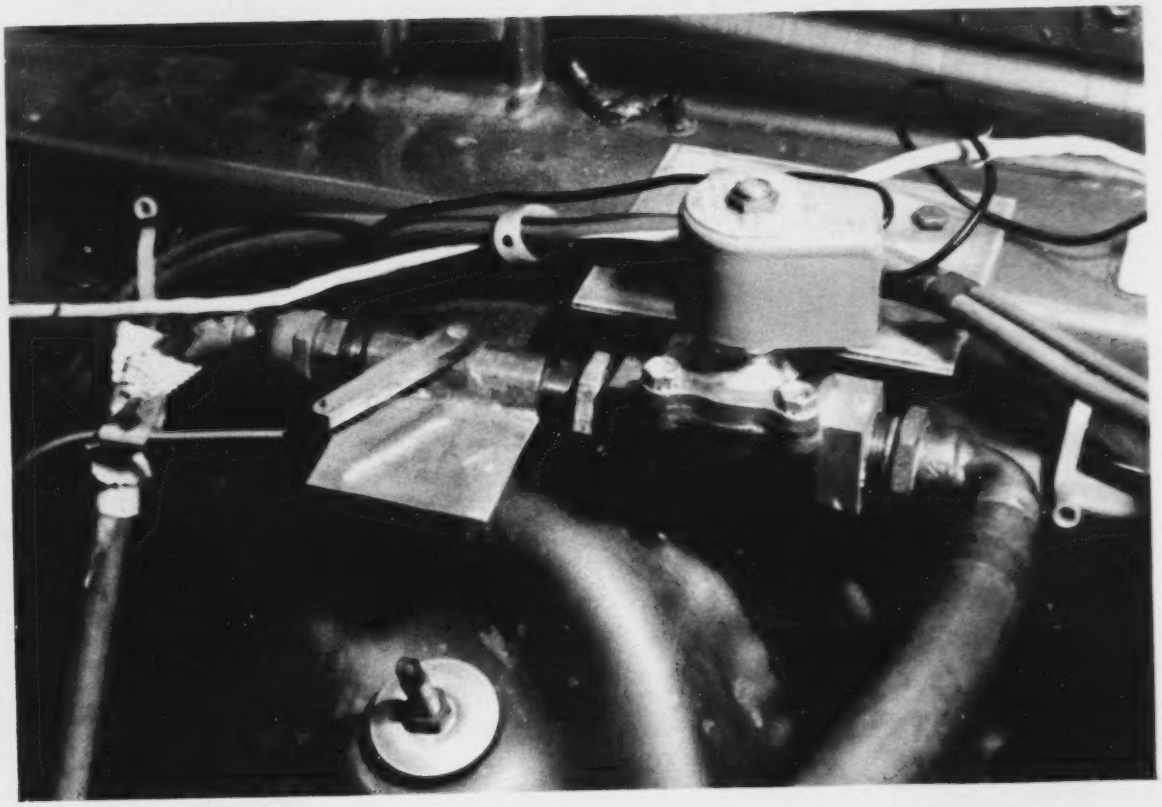


FIG. 14.
EXHAUST RECYCLE VALVING ARRANGEMENT